



Analysis of the anomalous events

$$e^+ e^- \rightarrow l^+ l^- \gamma \gamma$$

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Abstract

The $e^+ e^- \rightarrow l^+ l^- \gamma \gamma$ anomalous events, registered at *L3* detector at $e^+ e^-$ *CERN - LEP* collider have been analysed. It has been shown that the interpretation of such events as a manifestation of scalar (pseudoscalar) resonance with the mass of 60 GeV contradicts other experimental data.

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1 Introduction

Recently the *L3* collaboration (*CERN – LEP* collider) has reported four unusual events in the following reaction [1] :

$$e^+ e^- \rightarrow l^+ l^- \gamma \gamma. \quad (1)$$

The two photon invariant mass in all these events is about 60 GeV.

There are uncertainties in the interpretation of these events. According to the authors estimates [1] the probability that these events could be interpreted as the usual QED background is relatively small ($\sim 10^{-3}$, see [1]).

The production of the Standard Model Higgs of 60 GeV mass (with subsequent Higgs decay into two photons) accompanied by $l^+ l^-$ pair could be one of the possible explanation of the observed effect. However the probability of such process is very small ($\sim 10^{-5}$, see [2]). Indeed, one should expect the production of about one event of the Higgs boson with $M_H = 60$ GeV at 10^6 Z-bosons. Taking into account that $Br(H \rightarrow \gamma\gamma)$ is of 10^{-4} order of magnitude, the number of events of reaction (1) for 10^6 Z-bosons is about 10^{-4} . This value is 10^5 times less than one observed in the *L3* experiment.

The interpretation of these events via additional Higgs bosons (using the extension of Standard Model) also meets some difficulties (see [3], for example).

In this paper the analysis of the reaction (1) is carried out with the assumption of existence of scalar (pseudoscalar) resonance with mass about 60 GeV. The nature of this resonance (i.e. whether this resonance appears to be an elementary object of Higgs boson type or a composite one of quarkonium type) is not discussed here.

The interaction of such resonance with photon and Z -boson is considered in general with three arbitrary coupling constants ($R\gamma\gamma \rightarrow g_{\gamma\gamma}$; $R\gamma Z \rightarrow g_{\gamma z}$; $RZZ \rightarrow g_{zz}$). As it follows from this analysis the obtained results do not depend on the presence or absence of the possible interaction of this resonance with other particles (quarks, leptons, etc).

A possible production of such resonance in other interactions (for example in $Z \rightarrow \gamma R(\rightarrow \gamma\gamma)$ decay) has been analysed alongside with the process (1) for the sake of the corresponding coupling constants estimates. Such combined analysis of different experiments has made it possible to obtain the upper limits for coupling constants of resonance interaction with photon and Z -boson.

The paper is organized as follows. The resonance interactions with photon and Z -boson are considered in Section 2, and calculations of the necessary expressions for decay width and production cross section is given. Different experiments resulting in the appearance of this proposed resonance are analysed in Section 3. The main obtained results are presented in Conclusion.

2 Theoretical estimates

As it has been mentioned in Introduction the existence of scalar (pseudoscalar) resonance R with about 60 GeV mass is assumed for the analysis of reaction (1) events.

One can write rather general expressions for the $R\gamma\gamma$, $R\gamma Z$ and RZZ vertices taking into account the Lorentz- and gauge invariance constraints only :

$$R^+ \gamma\gamma = \frac{g_{\gamma\gamma}}{M_R} (g^{\mu\nu}(k_1 k_2) - k_1^\nu k_2^\mu) e_1^\mu e_2^\nu,$$

$$\begin{aligned}
R^- \gamma \gamma &= \frac{g_{\gamma\gamma}}{M_R} \epsilon^{\mu\nu\alpha\beta} k_1^\mu k_2^\nu e_1^\alpha e_2^\beta, \\
R^+ \gamma Z &= \frac{g_{\gamma z}}{M_R} (g^{\mu\nu}(k_1 k_2) - k_1^\nu k_2^\mu) e^\mu V^\nu, \\
R^- \gamma Z &= \frac{g_{\gamma z}}{M_R} \epsilon^{\mu\nu\alpha\beta} k_1^\mu k_2^\nu e^\alpha V^\beta, \\
R^+ Z Z &= g_{zz} M_Z g^{\mu\nu} V_1^\mu V_2^\nu, \\
R^- Z Z &= \frac{g_{zz}}{M_R} \epsilon^{\mu\nu\alpha\beta} k_1^\mu k_2^\nu V_1^\alpha V_2^\beta,
\end{aligned}$$

where $R^+(R^-)$ denotes scalar (pseudoscalar) resonance; k_1 and k_2 are momenta of two final photons (photon and Z -boson or two Z -bosons); $e^\nu(V^\nu)$ is the photon (Z -boson) polarization vector. The factor $1/M_R$ takes into account the dimensionless of coupling constants.

As it was mentioned in Introduction the nature of this resonance is not discussed. Therefore we do not consider possible types of interactions with other particles (quarks, leptons, etc.). Moreover, our analysis does not depend on the existence of such interactions as it will be shown below.

The basic process (1) cross section can be easily calculated from the mentioned above expressions for the vertices of resonance interactions with photon and Z -boson. Four Feynman diagrams describe this process (see Appendix for details). And cross section of this reaction depends on all the three coupling constants and also on branching ratio of R resonance decay into $\gamma\gamma$:

$$\sigma = f(g_{\gamma\gamma}; g_{\gamma z}; g_{zz}) Br(R \rightarrow \gamma\gamma) \quad (2)$$

where $Br(R \rightarrow \gamma\gamma) = \Gamma(R \rightarrow \gamma\gamma) / \Gamma_{tot}(R)$.

The expression for cross section is given in the Appendix.

In order to determine the effective coupling constants values separately we consider processes which may result in the appearance of hypothetical R -resonance. Let us also choose those processes in which R can decay into $\gamma\gamma$.

2.1 Two photon annihilation process

$$e^+ e^- \rightarrow e^+ e^- R (\rightarrow \gamma\gamma) \quad (3)$$

Diagrams with t -channel photon exchange will contribute substantially this process far from the Z -boson pole. And Z -boson contribution to the s -channel will be suppressed for a major extend. Weak interactions contribution to the rest diagrams is very small compared to QED contribution. Then we have in the equivalent photon approximation :

$$\sigma(e^+ e^- \rightarrow e^+ e^- R) = \eta^2 \frac{8\pi^2 \Gamma(R \rightarrow \gamma\gamma)}{s M_R} f\left(\frac{M_R^2}{s}\right),$$

where $\eta = \frac{\alpha}{2\pi} \ln\left(\frac{s}{4m_e^2}\right)$; $f(\omega) = \frac{1}{\omega} ((2 + \omega)^2 \ln(\frac{1}{\omega}) - 2(1 - \omega)(3 + \omega))$.

The corresponding expression for the process (3) cross section is the following :

$$\sigma(e^+ e^- \rightarrow e^+ e^- R (\rightarrow \gamma\gamma)) = \sigma(e^+ e^- \rightarrow e^+ e^- R) Br(R \rightarrow \gamma\gamma). \quad (4)$$

The decay width of R -resonance into two photons is :

$$\Gamma(R^+ \rightarrow \gamma\gamma) = \Gamma(R^- \rightarrow \gamma\gamma) = \frac{g_{\gamma\gamma}^2}{64\pi} M_R. \quad (5)$$

2.2 Z -boson decay into 3γ

One can obtain the upper limit for $g_{\gamma z}$ from the experimental value of $\Gamma(Z \rightarrow 3\gamma)$ [4] :

$$\Gamma(Z \rightarrow \gamma R(\rightarrow \gamma\gamma)) = \Gamma(Z \rightarrow \gamma R) Br(R \rightarrow \gamma\gamma) \leq \Gamma(Z \rightarrow 3\gamma). \quad (6)$$

where the expression for $\Gamma(Z \rightarrow \gamma R)$ is as follows :

$$\Gamma(Z \rightarrow \gamma R^+) = \Gamma(Z \rightarrow \gamma R^-) = \frac{g_{\gamma z}^2 m_Z (1 - \delta)^3}{96\pi\delta}, \quad (7)$$

here $\delta = (\frac{M_R}{M_Z})^2$.

2.3 $\nu\bar{\nu}$ pair production with two photons

$$e^+ e^- \rightarrow \nu\bar{\nu} R(\rightarrow \gamma\gamma) \quad (8)$$

The cross section of this process is calculated analogically to one of basic process (1) (see Appendix).

The analogous $\nu\bar{\nu}\gamma\gamma$ final state can be produced in the following reaction :

$$e^+ e^- \rightarrow \gamma R(\rightarrow \gamma Z^*(\rightarrow \nu\bar{\nu})).$$

But the contribution of these diagrams is negligible due to very small probability of the $R \rightarrow \gamma Z^*(\rightarrow \nu\bar{\nu})$ decay compared to $R \rightarrow \gamma\gamma$ decay.

3 The analysis of the experimental data

One can obtain the upper limits for $g_{\gamma\gamma}$, $g_{\gamma z}$ and g_{zz} coupling constants separately using the experimental data [1], [4] and [5] for the processes (3), (6) and (8).

3.1 *R-resonance production in e^+e^- annihilation at the KEK energies*

Analysing process (3) we used the following experimental information [5] : no events were observed, i.e. $N_{ev} \leq 1$; the total integrated luminosity is $\mathcal{L} = 60 pb^{-1}$ and $\sqrt{s} = 70$ GeV.

From the expression (4) and $N_{ev} \leq 1$ constraint the following inequality is obtained :

$$1.17 \cdot 10^5 g_{\tau\tau}^2 Br(R \rightarrow \gamma\gamma) \leq 1$$

or

$$g_{\tau\tau} \sqrt{Br(R \rightarrow \gamma\gamma)} \leq 2.92 \cdot 10^{-3}. \quad (9)$$

3.2 *$Z \rightarrow 3\gamma$ decay*

While analysing this decay we used the following experimental data for $Z \rightarrow 3\gamma$ decay [4] :

$$Br(Z \rightarrow 3\gamma) \leq 6.6 \cdot 10^{-6}.$$

We can obtain the following upper limit for coupling constant $g_{\gamma z}$ from this data and expressions (6) and (7) :

$$g_{\gamma z} \sqrt{Br(R \rightarrow \gamma\gamma)} \leq 0.036. \quad (10)$$

3.3 $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ reaction

The upper limits for g_{zz} can be obtained from the value of the process (8) cross section on the basis of the following experimental information [1] : no events were observed, i.e. $N_{ev} \leq 1$; the total integrated luminosity is $\mathcal{L} = 21 pb^{-1}$ and $\sqrt{s} \simeq 92$ GeV. As a result we obtain :

1. For scalar R^+ -resonance :

$$(1.64 \cdot 10^{-3} g_{\gamma z}^2 + 4.90 g_{zz}^2) Br(R \rightarrow \gamma\gamma) \leq 1.$$

2. For pseudoscalar R^- -resonance :

$$(1.0 \cdot 10^{-3} g_{\gamma z}^2 + 0.47 g_{zz}^2) Br(R \rightarrow \gamma\gamma) \leq 1.$$

The $g_{\gamma z}$ coupling constant contribution to the above inequalities is negligible (see (10)). It enables to obtain the following upper limit for the constant g_{zz} :

1. In the case of R^+ :

$$g_{zz} \sqrt{Br(R \rightarrow \gamma\gamma)} \leq 0.451. \quad (11)$$

2. In the case of R^- :

$$g_{zz} \sqrt{Br(R \rightarrow \gamma\gamma)} \leq 1.46. \quad (12)$$

Now we can proceed to the calculation of the number of the reaction (1) events with the help of the expression for the basic process cross section. We use the following

data [1], namely : there are 3 detected events with $\mu^+\mu^-\gamma\gamma$ final state at $\sqrt{s} \simeq 92$ GeV and the total integrated luminosity of $\mathcal{L} = 27 \text{ pb}^{-1}$ and $(m_{\mu^+\mu^-})_{\min} = 18$ GeV.

As a result we obtain the theoretical estimates for the number of events for basic reaction (1).

1. For the scalar R^+ -resonance :

$$N_{th}^+ = (0.15g_{\gamma\gamma}^2 + 72.8g_{\gamma z}^2 + 0.76g_{zz}^2 - 9.16 \cdot 10^{-4}g_{\gamma\gamma}g_{\gamma z} + 9.38 \cdot 10^{-5}g_{\gamma\gamma}g_{zz} + 0.99g_{\gamma z}g_{zz})Br(R \rightarrow \gamma\gamma). \quad (13)$$

2. For the pseudoscalar R^- -resonance :

$$N_{th}^- = (0.10g_{\gamma\gamma}^2 + 49.0g_{\gamma z}^2 + 0.0684g_{zz}^2 - 5.21 \cdot 10^{-4}g_{\gamma\gamma}g_{\gamma z} - 2.30 \cdot 10^{-5}g_{\gamma\gamma}g_{zz} - 0.247g_{\gamma z}g_{zz})Br(R \rightarrow \gamma\gamma). \quad (14)$$

The theoretical number of events for the process (1) can be obtained substituting of the mentioned limits for coupling constants (9)-(12) into eqs. (13) and (14) . As a result we obtain for the scalar(pseudoscalar) $R^+(R^-)$ -resonance :

$$N_{th}^+(N_{th}^-) \leq 0.265(0.197). \quad (15)$$

that gives an order of magnitude less events than measured by the $L3$ -collaboration.

The obtained theoretical estimate eqs. (15) can be slightly increased choosing $M_R = M_{\min}(\gamma\gamma) = 58.2$ GeV (the minimal measured two photon mass) instead of $M_R = 60$ GeV. As a result one can obtain instead of eqs. (15) for the

scalar(pseudoscalar) $R^+(R^-)$ -resonance :

$$N_{th}^+(N_{th}^-) \leq 0.288(0.220). \quad (16)$$

that is still essentially smaller than experimental value ($N_{exp} = 3$).

It should be noted that the reaction (1) cross section and the correspondent number of events from (13), (14) is a logarithmic function only of the minimal invariant mass of final leptons (see Appendix). Therefore another choice of $(m_{\mu^+\mu^-})_{min}$ (2 GeV, for example) results in an increase of the cross section (and corresponding number of events) but no more than two times. That is still smaller than experimental value.

It is necessary to note that the coupling constants estimates (see eqs. (9) – (12)) contain the products of constants squared and branching ratio of R -resonance two photon decay. The corresponding products of coupling constants and $Br(R \rightarrow \gamma\gamma)$ enter the final expression (13) and (14) for the number of events. Thus our analysis is independent of the $Br(R \rightarrow \gamma\gamma)$ value and the presence (or absence) of possible interactions of the studied R -resonance with other particles as well.

4 Conclusions

The $e^+e^- \rightarrow l^+l^-\gamma\gamma$ anomalous events, registered at $L3$ detector at e^+e^- CERN – LEP collider have been analysed under assumption of general type interactions of the scalar (pseudoscalar) R -resonance with photons and/or Z -bosons.

We obtained the upper limits for the effective coupling constants of interaction of this resonance with photon and Z -boson separately from analysis of the following reactions :

1. $g_{\gamma\gamma}\sqrt{Br(R \rightarrow \gamma\gamma)} \leq 2.92 \cdot 10^{-3}$ from reaction $e^+ e^- \rightarrow e^+ e^- \gamma\gamma$ (at KEK energies).
2. $g_{\gamma Z}\sqrt{Br(R \rightarrow \gamma\gamma)} \leq 0.036$ from the process $Z \rightarrow \gamma\gamma\gamma$.
3. $g_{zz}\sqrt{Br(R^+(R^-) \rightarrow \gamma\gamma)} \leq 0.451(1.46)$ from reaction $e^+ e^- \rightarrow \nu\bar{\nu}\gamma\gamma$.

The obtained upper limits of coupling constants make it possible to estimate the theoretical number of events ($N_{th} = 0.197 - 0.288$), which an order of magnitude smaller than the experimental data of L3-collaboration ($N_{th} = 3$). Therefore our analysis says that these events might be only due to usual QED background processes (as it is mentioned in [1]). have been analysed. And the interpretation of such events as a manifestation of scalar (pseudoscalar) resonance with the mass of 60 GeV contradicts other experimental data.

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Appendix

In this Appendix we present the expressions for the cross-section for the following reaction :

$$e^+(l_1)e^-(l_2) \rightarrow f(l_3)\bar{f}(l_4)R(\rightarrow \gamma\gamma),$$

where the 4-momenta of the particles are given in the parenthesis.

This process is described by four Feynman diagrams. The first (second) diagram $M_1(M_2)$ corresponds to e^+e^- annihilation via photon with production of R and $\gamma^*(Z^*) \rightarrow f\bar{f}$. The third (fourth) one $M_3(M_4)$ corresponds to e^+e^- annihilation via Z -boson with production of R and $\gamma^*(Z^*) \rightarrow f\bar{f}$. Below we present the expressions for these amplitudes :

1. For scalar resonance production:

$$\begin{aligned} M_1 &= \frac{g_{\gamma\gamma}}{M_R} f^{\alpha\beta} \frac{1}{q_1^2 q_2^2} L_1^\alpha L_2^\beta; \quad M_2 = \frac{g_{\gamma Z}}{M_R} f^{\alpha\beta} \frac{1}{q_1^2 Z_2} d_2^{\beta\nu} L_1^\alpha K_2^\nu; \\ M_3 &= \frac{g_{\gamma Z}}{M_R} f^{\alpha\beta} \frac{1}{q_2^2 Z_1} d_1^{\alpha\mu} K_1^\mu L_2^\beta; \quad M_4 = g_{ZZ} M_Z \frac{1}{Z_1 Z_2} g^{\alpha\beta} d_1^{\beta\nu} d_2^{\alpha\mu} K_1^\mu K_2^\nu; \end{aligned}$$

where the following notations are introduced :

$$\begin{aligned} f^{\alpha\beta} &= (q_1 q_2) g^{\alpha\beta} - q_1^\beta q_2^\alpha, \quad d_{1(2)}^{\alpha\beta} = g^{\alpha\beta} - \frac{q_{1(2)}^\alpha q_{1(2)}^\beta}{M_Z^2}, \\ Z_{1(2)} &= (q_{1(2)}^2 - M_Z^2) + i M_Z \Gamma_Z, \quad q_1^\mu = l_1^\mu + l_2^\mu, \quad q_2^\mu = l_3^\mu + l_4^\mu, \\ L_1^\alpha &= e \bar{u}(l_1) \gamma^\alpha u(-l_2), \quad L_2^\alpha = e \bar{u}(l_3) \gamma^\alpha u(-l_4), \\ K_1^\alpha &= \bar{u}(l_1) \gamma^\alpha (a_1 + b_1 \gamma^5) u(-l_2), \quad K_2^\alpha = \bar{u}(l_3) \gamma^\alpha (a_2 + b_2 \gamma^5) u(-l_4), \end{aligned}$$

2. For pseudoscalar resonance production :

$$\begin{aligned} M_1 &= \frac{g_{\gamma\gamma}}{M_R} t^{\alpha\beta} \frac{1}{q_1^2 q_2^2} L_1^\alpha L_2^\beta; \quad M_2 = \frac{g_{\gamma z}}{M_R} t^{\alpha\beta} \frac{1}{q_1^2 Z_2} d_2^{\beta\nu} L_1^\alpha K_2^\nu; \\ M_3 &= \frac{g_{\gamma z}}{M_R} t^{\alpha\beta} \frac{1}{q_2^2 Z_1} d_1^{\alpha\mu} K_1^\mu L_2^\beta; \quad M_4 = \frac{g_{zz}}{M_R} \frac{1}{Z_1 Z_2} t^{\alpha\beta} d_1^{\beta\nu} d_2^{\alpha\mu} K_1^\nu K_2^\mu; \end{aligned}$$

where $t^{\alpha\beta} = \epsilon^{\alpha\beta\lambda\sigma} q_1^\lambda q_2^\sigma$, other notations are presented above.

The final expression for the cross section production of scalar R^+ -resonance is as follows (we put all fermions massless) :

$$\sigma = \frac{\alpha^2}{24\pi s} (g_{\gamma\gamma}^2 F_1 + g_{\gamma z}^2 F_2 + g_{zz}^2 F_3 + g_{\gamma\gamma} g_{\gamma z} F_4 + g_{\gamma\gamma} g_{zz} F_5 + g_{\gamma z} g_{zz} F_6),$$

where

$$\begin{aligned} F_1 &= e_1^2 e_2^2 A_2; \\ F_2 &= \frac{g^2 e_2^2 (a_1^2 + b_1^2)}{\epsilon} A_2 + g^2 e_1^2 (a_2^2 + b_2^2) (A_3 + A_4) + 2g^2 e_1 e_2 a_1 a_2 A_4; \\ F_3 &= \frac{g^4 (a_1^2 + b_1^2) (a_2^2 + b_2^2)}{6\epsilon} A_1; \quad F_4 = 2g e_1^2 e_2 a_2 A_3; \\ F_5 &= 2g^2 e_1 e_2 a_1 a_2 A_5; \quad F_6 = \frac{2g^3 e_2 a_2 (a_1^2 + b_1^2)}{\epsilon} A_6. \end{aligned}$$

$$\begin{aligned} A_1 &= \frac{u_0}{2} (5\delta - 23 - \lambda) + L_0 (2\delta^2 - 14\delta) + J_0 \sqrt{\delta(4 - \delta)}; \\ A_2 &= \frac{u_0}{6\delta} (3 + 8\delta - 5\lambda - 3\delta^2 + \delta\lambda) + \frac{L_0}{3\delta} (3\delta^2 - 9\delta - \delta^3) - \frac{u_0^3}{9\delta} \\ &\quad + \frac{L_1}{3\delta} (1 - \delta^2) (1 + \delta); \\ A_3 &= \frac{u_0}{6\delta} (13\delta - 3\delta^2 + \delta\lambda - 6\lambda - 7) + \frac{L_0}{3\delta} (6\delta^2 - \delta^3 - 18\delta) - \frac{u_0^3}{9\delta} \\ &\quad - \frac{J_0}{3\delta} (6 - 4\delta + \delta^2) \sqrt{\delta(4 - \delta)}; \\ A_4 &= \frac{u_0}{6\delta(1 - \delta)} (-7\delta^2 + 24\delta + \delta\lambda - 23) + \frac{L_0}{3\delta} (3\delta^2 - 12\delta + 6) \end{aligned}$$

$$\begin{aligned}
& + \frac{J_0}{3\delta} \sqrt{\frac{\delta}{4-\delta}} (3\delta^2 - 18\delta + 30); \\
A_s &= u_0 \frac{2\delta - 3}{\sqrt{\delta}(4-\delta)} - \frac{L_0}{\sqrt{\delta}} (2\delta - 2) + J_0 \frac{5-\delta}{\sqrt{4-\delta}}; \\
A_a &= \frac{u_0}{2\sqrt{\delta}} (3 - 3\delta + \lambda) + \frac{L_0}{\sqrt{\delta}} (4\delta - \delta^2) + J_0 \sqrt{4-\delta} (2-\delta); \\
L_0 &= \ln\left(\frac{3\sqrt{\delta}}{1+\delta-\lambda-u_0}\right), \quad L_1 = \ln\left(\frac{(1-\delta)^2 + (1-\delta)u_0 - (1+\delta)\lambda}{2\lambda\sqrt{\delta}}\right); \\
J_0 &= \frac{\pi}{2} - A \sin\left(\frac{(3-\delta+\lambda)\sqrt{\delta}}{2(1-\delta)}\right), \quad u_0 = \sqrt{(1-\delta)^2 - 2(1+\delta)\lambda + \lambda^2}
\end{aligned}$$

where

$$g = \frac{1}{\sin(2\theta_W)}, \quad \delta = \frac{M_R^2}{s}, \quad \epsilon = \left(\frac{\Gamma_Z}{\sqrt{s}}\right)^2, \quad \lambda = \left(\frac{q_{\min}^2}{s}\right),$$

$e_{1(2)}$ is the fermion charge (in electron's charge units); $a_{1(2)}, b_{1(2)}$ are the vector and axial coupling constants of initial (final) fermions with Z -boson; $\sqrt{q_{\min}^2} = (m_{\mu^+\mu^-})_{\min}$ is the minimal value of the invariant mass of final leptons. The expression for integrated cross section of pseudoscalar resonance production has the analogous form as for scalar one, and we do not include it in the paper.